New sub-millimeter limits on dust in the 55 Cancri planetary system

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ABSTRACT

We present new, high-sensitivity sub-millimeter observations towards 55 Cancri, a nearby G8 star with one, or possibly two, known planetary companion(s). Our 850 μm map, obtained with the SCUBA instrument on the James Clerk Maxwell Telescope, shows three peaks of emission at the 2.5 mJy level in the vicinity of the star's position. However, the observed peaks are $25''$–$40''$ away from the star and a deep R-band optical image reveals faint point sources that coincide with two of the sub-millimeter peaks. Thus, we do not find evidence for dust emission spatially associated with 55 Cancri. The excess 60 μm emission detected with ISO may originate from one or more of the 850 μm peaks that we attribute to background sources. Our new results, together with the HST/NICMOS coronographic images in the near-infrared, place stringent limits on the amount of dust in this planetary system, and argue against the existence of a detectable circumstellar dust disk around 55 Cnc.

Subject headings: planetary systems – stars : individual (55 Cnc) – circumstellar matter

1. Introduction

Dusty disks that are believed to be the debris of planetary formation have now been imaged at infrared and sub-millimeter wavelengths around several nearby main-sequence stars including β Pictoris, HR 4796A, Vega, Fomalhaut and ϵ Eridani (Smith & Terrile 1984; Holland et al. 1998; Jayawardhana et al. 1998; Greaves et al. 1998). These disks may be young analogs of the Kuiper Belt in our solar system (Jewitt & Luu 2000). The $\sim$5-Gyr-old

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(Gonzalez & Vanture 1998; Baliunas et al. 1997) G8V star 55 Cancri (HR 3522; HD 75732), at a distance of 13 pc, has attracted much attention in recent years for having planet(s) as well as a possible dust disk. The only other example reported to date of a planet co-existing with a disk is ϵ Eri, which has a well-resolved, prominent disk in the sub-millimeter images (Greaves et al. 1998). However, the presence of a giant planet around ϵ Eri (Hatzes et al. 2000) is difficult to establish with radial velocity measurements because of the high level of stellar chromospheric activity and possible face-on orientation of the planet orbit. On the other hand, in the case of 55 Cnc, it is the putative disk that is in dispute.

55 Cnc harbors an inner planet with $M \; sin \; i = 0.84$ M_{Jup} in an orbit with a semi-major axis of 0.11 AU (Butler et al. 1997). There is evidence for a second planet at several AU in the form of a residual drift in the radial velocity over the past 10 years (Marcy & Butler 1998; Fischer et al. 2001). It has been noted that 55 Cnc –along with 14 Her, another planet-bearing star– is one of the two most metal-rich stars in the solar neighborhood, with [Fe/H]$\geq$+0.4, perhaps suggesting a causal link between planets and the metallicity of the parent star (Gonzalez & Vanture 1998; Gonzalez, Wallerstein & Saar 1999).

Dominik et al. (1998) first presented evidence for a Vega-like disk around 55 Cnc based on *Infrared Space Observatory* (ISO) measurements between 25 μm and 180 μm. They detected the stellar photosphere at 25 μm, significant excess emission at 60 μm, and infrared cirrus at 135 and 180 μm. Trilling & Brown (1998) and Trilling, Brown & Rivkin (2000) confirmed the debris disk interpretation of the far-infrared data by reporting a resolved scattered light disk out to a radius of 3.24$''$ (40 AU) in ground-based, near-infrared, coronographic images. They estimated the disk position angle as 50 $\pm$ 10 degrees, inclination 27^{+8}_{-11} degrees and minimum dust mass 0.4 M_{Earth}. Our previous sub-millimeter observations detected 850 μm flux of 2.8$\pm$0.5 mJy and 450 μm flux of 7.9$\pm$4.2 mJy in the direction of 55 Cnc, which implied a dust mass at least 100 times lower than the Trilling & Brown (1998) estimate. Our mid-infrared observations at 10 μm and 18 μm showed no excess emission above the stellar photospheric level (Jayawardhana et al. 2000). Using the NICMOS near-infrared camera on the *Hubble Space Telescope* (HST), Schneider et al. (2001) were not able to confirm the results of Trilling and co-workers down to a flux level that is 10 times lower.

Here we report new, extremely sensitive sub-millimeter observations in the vicinity of 55 Cnc using the Submillimeter Common User Bolometer Array (SCUBA) on the James Clerk Maxwell Telescope (JCMT). We find three faint sources of emission, none of which is centered exactly on 55 Cnc. Our results, combined with the NICMOS observations, place strong limits on the amount of dust emission associated with the 55 Cnc planetary system.

2. Observations and Results

The 850 μm observations of 55 Cnc presented here were carried out with the SCUBA instrument (Holland et al. 1999) on the JCMT on Mauna Kea, Hawaii. The data were obtained over several observing runs in 1999-2000 using the SCUBA photometry mode. In total, there were 31 separate photometric observations at two different pointings in the vicinity of 55 Cnc for a total on-source integration time of 7.1 hours. Zenith atmospheric opacities at 850 μm ranged from 0.10 to 0.35. When coadded together, the maps were noise weighted to account for the range of conditions. Observations of Uranus were used for calibrations. Pointing accuracy was $2''$, which is small compared with the beam size of $15''$ at 850 μm (full-width at half-maximum; FWHM). The data were reduced using the SCUBA User Reduction Facility (Jenness & Lightfoot 1998). The co-added map is shown in Figure 1.

The 850 μm map shows three obvious peaks of emission at the $\sim$2.5 mJy level. Their fluxes and positions are given in Table 1. The rest of the field is rather flat with an rms noise of about 0.4 mJy. Each of the peaks is $25''$–$40''$ (325–500 AU) away from 55 Cnc. There is no emission exactly coincident with the position of 55 Cnc.

We also obtained optical R-band CCD images at the University of Hawaii 2.2-meter telescope on Mauna Kea on 31 January 2000. An optical coronograph (Kalas & Jewitt 1996) blocked the stellar point-spread-function (PSF) at the focal plane using a hard-edged occulting spot with $6.5''$ diameter. A Lyot stop at a re-imaged pupil plane suppressed diffracted light from the telescope mirrors and support structures. The imaging camera was a TEK 2048×2048 CCD with a plate scale of $0.407''$ per pixel and with a circular field of view $5.5'$ in diameter. Thirty-two frames with 20 seconds integration time each were obtained for 55 Cnc. Immediately after these observations we imaged a nearby bright star HR 3521 with the same instrumental configuration. These data serve as a reference for subtracting the 55 Cnc PSF.

After bias-subtraction and flatfielding, we selected 20 frames from the 55 Cnc data that were well-centered behind the occulting spot and that had field star PSF's with FWHM in the range $1.0-1.2''$. These frames were median-combined to produce an image of 55 Cnc with 400 seconds cumulative integration time. The HR 3521 data was for the most part unsuitable for subtracting the 55 Cnc PSF due to poor centering of HR 3521 behind the occulting spot. However, one HR 3521 frame (15 seconds integration) was well-centered and adopted as the PSF reference source. We azimuthally smoothed this PSF by rotating the image in 20 degree increments and median-combining the resulting frames. The azimuthally smoothed PSF was subtracted from the original HR 3521 frame, revealing residual light along a southeast-northwest axis. The residual halo of the self-subtracted PSF is probably

due to a combination of instrumental and atmospheric aberrations.

The azimuthally smoothed HR 3521 PSF was registered, scaled and subtracted from 55 Cnc (Fig. 2). The subtracted 55 Cnc PSF also appears to have residual light symmetrically distributed about the occulting spot along a southeast-northwest axis. This axis is perpendicular to the position angle of the disk reported by Trilling & Brown (1998). The residual PSF halo extends from approximately $4''$ to $16''$ radius, decreasing approximately with the fourth power of radius, and with surface brightness in the range 17.5−23.0 mag arcsec^{-2}. Trilling & Brown (1998) report an H-band disk surface brightness that falls below 24 mag arcsec^{-2} beyond $4''$ radius. Our data do not have the sensitivity to detect extended nebulosity fainter than 23.0 mag arcsec^{-2}.

We performed a second PSF subtraction using an azimuthally smoothed version of the 55 Cnc image as described above for HR 3521. This self-subtraction of 55 Cnc also resulted in residual light along a southeast-northwest axis. Because the residual light appears in both the 55 Cnc and HR 3521 self-subtractions, we attribute it purely to instrumental and atmospheric aberrations. The dominant source is most likely a static aberration such as focus error. Finally, as a third PSF subtraction, we selected the best 55 Cnc frame and registered, scaled and subtracted the unsmoothed HR 3521 frame. Though the result contains significantly greater noise than the image in Fig. 2, the residual light does not contain significant azimuthal asymmetry.

Three point sources are detected in the R-band image within a $40''$ radius surrounding 55 Cnc (Fig. 2). Their positions are indicated by white boxes in Fig. 1 to show their relation to the 850 μm emission. Table 1 lists the magnitudes of the R-band sources and their offsets in arcseconds from the centroids of 850 μm emission. The two point sources north of 55 Cnc may be optical counterparts of the 850 μm sources. No object was detected in the optical data that corresponds to the position of the sub-millimeter peak south of 55 Cnc. The 3σ point source sensitivity of the optical data is m_R = 22.2 mag, as determined by injecting artificial point sources near the positions of the optically detected sources and the 850 μm peaks.

3. Discussion

Our sub-millimeter observations of the field around 55 Cnc reveal three faint sources of emission at the $\sim$2.5 mJy level. The separation between 55 Cnc and each of the 850 μm peaks is approximately two beam widths and thus unambiguously non-coincident with the star. The spatial association of two of the sub-millimeter peaks with optically detected point

sources (Fig. 2) makes it unlikely that the 850 μm peaks are components of an extended dust ring around 55 Cnc.

According to the galaxy counts derived by Blain et al. (1999) from their deep sub-millimeter survey, one would expect 3$\pm$1 galaxies brighter than 1 mJy at 850 μm in a patch of the sky with a 40$''$ radius. Thus, all of the peaks in our 850 μm map could be background galaxies. In that case, the optical point sources could either be bright compact nuclei of the galaxies or stars whose positional coincidence with the sub-millimter peaks is simply due to chance alignments in the line of sight. Without additional color information or spectra, we are not able to comment further on the nature of these sources.

If the sub-millimeter peaks are due to unrelated sources, which appears likely, then we can place an upper limit of $\sim$0.4 mJy to the 850 μm emission from within $\sim$100 AU of 55 Cnc itself. Since the sub-millimeter flux is relatively insensitive to the temperature of dust grains, we can use it to derive a limit on the dust mass associated with 55 Cnc. Following Jura et al. (1995), the dust mass M_d is given by

$$M_d = F_\nu R^2 \lambda^2 / \left[2kT_{gr} K_{abs}\left(\lambda\right)\right], \tag{1}$$

if R denotes the distance from the sun to 55 Cnc. Assuming a dust absorption coefficient $K_{abs}(\lambda)$ between 1.7 and 0.4 cm^2 g^{-1} at 850 μm (Greaves et al. 1998), we obtain an upper limit to the dust mass of $1{-}7{\times}10^{-4}$ M$_{Earth}$, assuming a disk temperature range T= 100-130 K. The lower value of $K_{abs}(\lambda)$ is suggested by models of large, icy grains (Pollack et al. 1994), while the higher estimate has been used for previous observations of debris disks (Holland et al. 1998). It is important to point out that sub-millimeter observations are not sensitive to very large grains or planetesimals, which could dominate the total mass while adding little sub-millimeter emission. Therefore, our dust mass estimate is only a lower limit to the total mass, and does not rule out a Kuiper Belt analog around 55 Cnc comprised of larger particles.

HST/NICMOS coronographic observations by Schneider et al. (2001) at 1.1 μm did not detect a dust disk around 55 Cnc down to a flux level 10 times below that reported by Trilling and co-workers. Schneider et al. also searched for and failed to find a suggested flux-excess anisotropy in the ratio of 1.7 : 1 in the circumstellar background along and orthogonal to the plane of the putative disk. They concluded that, if such a disk does exist, its surface brightness in the near-infrared (and thus its dust mass) would have to be an order of magnitude lower than the Trilling et al. estimate.

Our new limit on the dust mass in the 55 Cnc planetary system is a factor of $\sim$7 lower than that reported by Jayawardhana et al. (2000), which was already a factor of $\sim$100

below the value reported by Trilling & Brown (1998) based on near-infrared scattered-light observations. We have now established that our previous sub-millimeter "detection" was not exactly coincident with 55 Cnc, but close to one of the peaks (source 1) in Figure 1. The pointing center used by Jayawardhana et al. (2000) was fortuitously close to this source due to a coordinate transcription error. Given the large ISO beam size of $45'' \times 45''$ per detector element, it is plausible that the Dominik et al. (1998) ISO detection at 60 μm also originates from one or more of these nearby, likely unrelated sources, and is not due to a dust disk around 55 Cnc.

In light of our results, those of Schneider et al. (2001), and the possibility of an unrelated source accounting for the ISO detection, there is little evidence for a dust disk around 55 Cnc other than the scattered-light coronographic images of Trilling & Brown (1998). The limits on the amount of small dust particles in the 55 Cnc planetary system from sub-millimeter and HST/NICMOS measurements are inconsistent with the Trilling & Brown (1998) estimate by a factor of 10 at best and 700 at worst. As Schneider et al. suggests, the most likely explanation for this significant discrepancy is that the detection reported by Trilling & Brown (1998) is spurious.

4. Summary

We have obtained sensitive sub-millimeter observations towards (and around) the 55 Cnc planetary system. We detect three peaks at the 2.5 mJy level in our 850 μm map that are offset from 55 Cnc by $25-40''$. Optical coronagraphic observations show three point sources over the same region, with two sources north of 55 Cnc approximately aligned with two 850 μm peaks. These peaks are likely unrelated background sources. Our results, together with the HST/NICMOS observations of Schneider et al. (2001), place stringent limits on the amount of dust in the 55 Cnc system, and are inconsistent with the existence of a circumstellar dust disk as reported by Dominik et al. (1998) and Trilling & Brown (1998).

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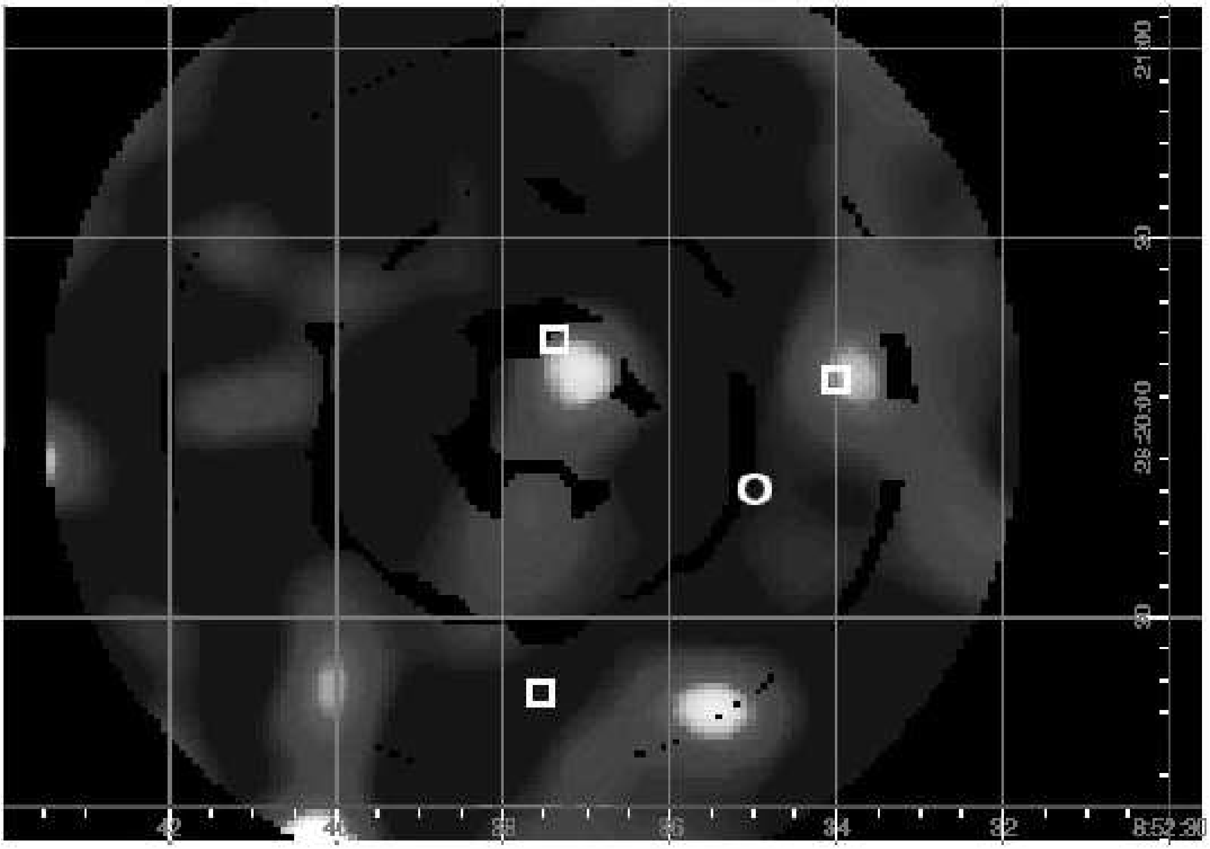

Fig. 1.— JCMT/SCUBA 850 μm map of the region surrounding 55 Cnc. The star's position is marked by the white circle. Positions of optical R-band sources are marked by white boxes. The map is produced from photometry observations at two different pointings. Each individual pointing produces a map with concentric rings. Even with two separate pointings, combined with the effects of sky rotation, a fully-sampled map is not produced and hence residual holes are evident.

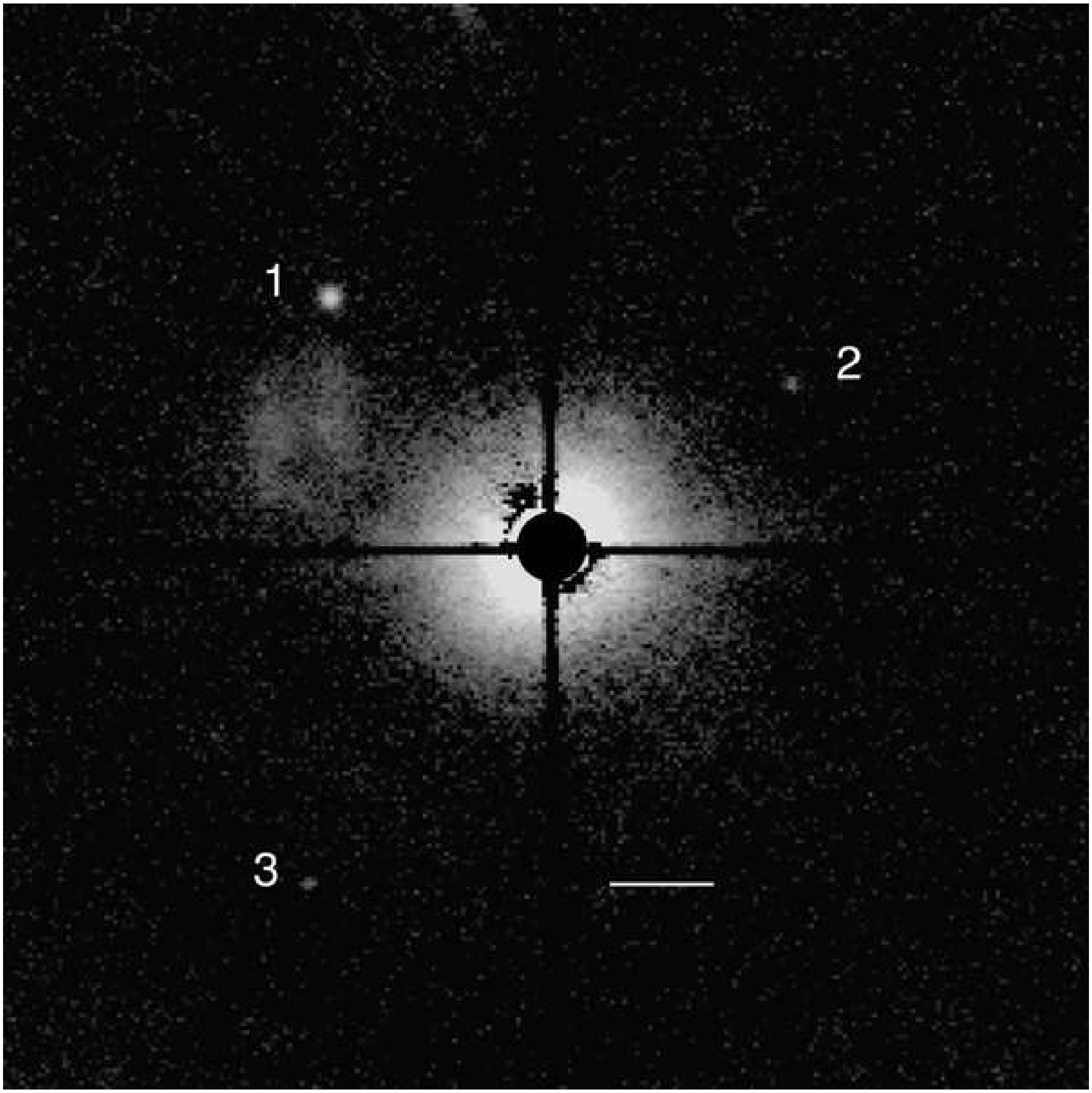

Fig. 2.— R-band coronagraphic image of 55 Cnc after PSF subtraction. North is up, East is left, and the bar represents 10″. A 6.5″ diameter, hard-edged occulting spot is supported by four wires at the telescope focal plane. Spurious instrumental scattered light is evident as an extended feature northeast of 55 Cnc and south of Source 1.

TABLE 1

POSITIONS AND FLUXES OF SUB-MM AND OPTICAL SOURCES

	Sub-mm			Optical			Difference (arcsec)	
	RA (2000)	Dec (2000)	850 μm flux	RA (2000)	Dec (2000)	R mag.	RA	Dec
Source 1	08:52:37.1	28:20:09.0	2.7 mJy	08 52 37.4	+28 20 14.6	19.0	4.0	5.6
Source 2	08:52:33.8	28:20:09.0	2.4 mJy	08 52 34.0	+28 20 06.3	21.1	4.0	2.7
Source 3	08:52:35.4	28:19:16.0	2.8 mJy	08 52 37.5	+28 19 18.2	21.5	29.1	2.4